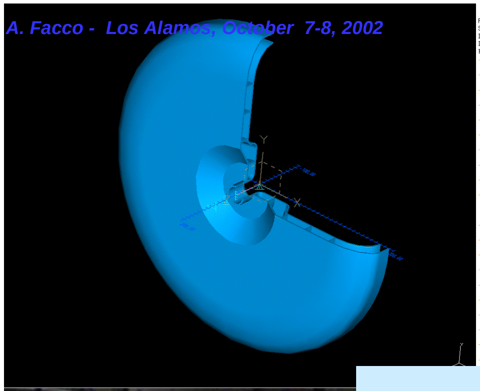
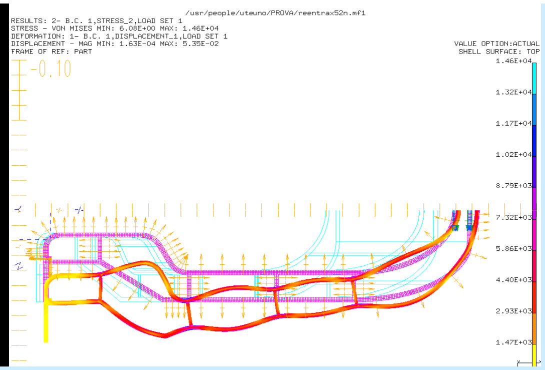
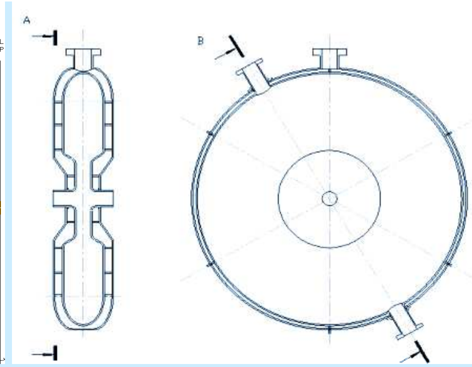
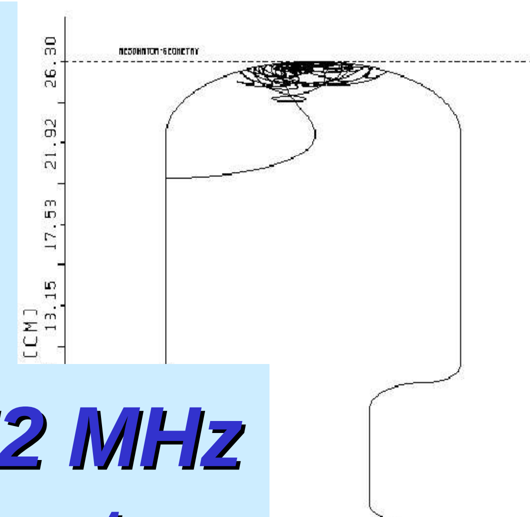
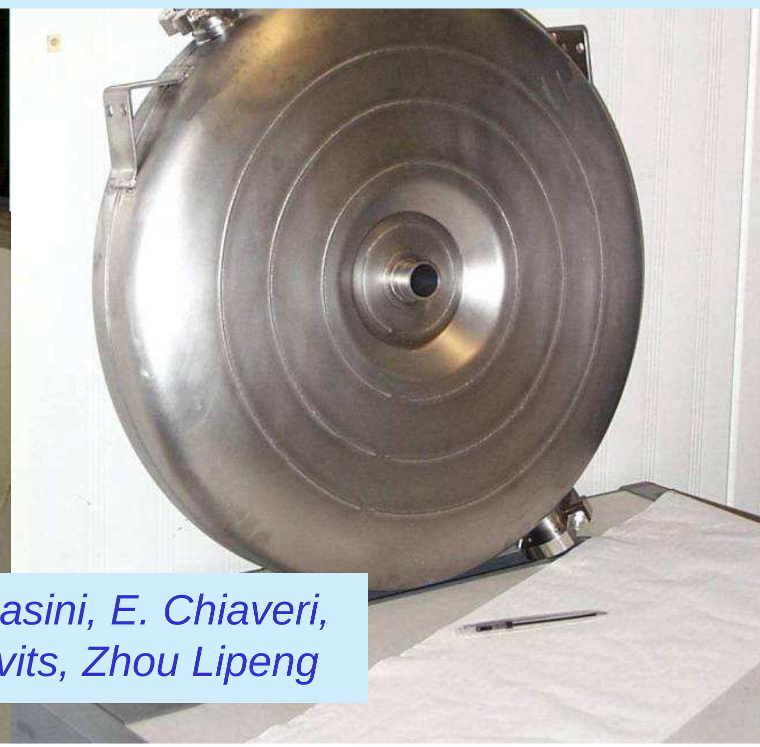








Development of a low-β , 352 MHz Superconducting Reentrant Cavity at LNL



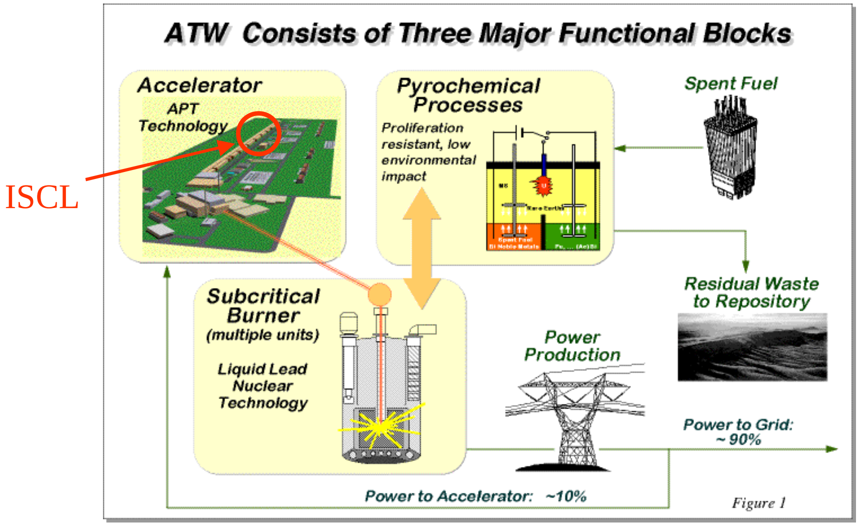
A. Facco, V. Zviagintsev, M. Pasini, E. Chiaveri,
R.Losito, F. Scarpa, D. Berkovits, Zhou Lipeng

Introduction

- We are developing low-β superconducting cavities for ADS applications (TRASCO)
- The TRASCO accelerator is a 1 GeV, 30 mA proton linac
- The intermediate energy part, 5-100 MeV, works at 352 MHz

- <u>Important constraint</u>: ADS systems with sub-critical reactors do not tolerate beam interruptions longer than ~1 s

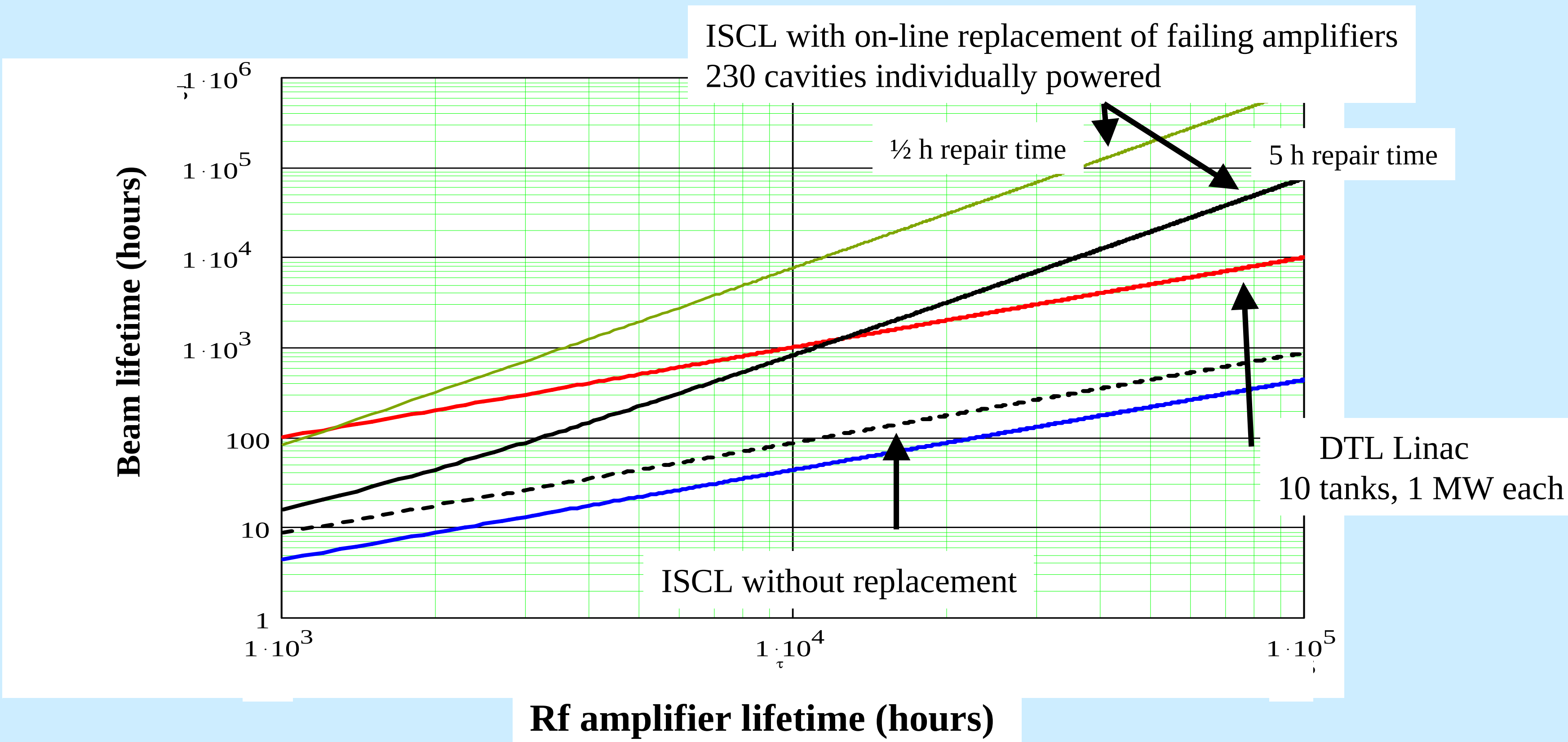
Accelerator Transmutation of Waste



Aim: Energy production and waste transmutation by means of an accelerator driven sub -critical reactor

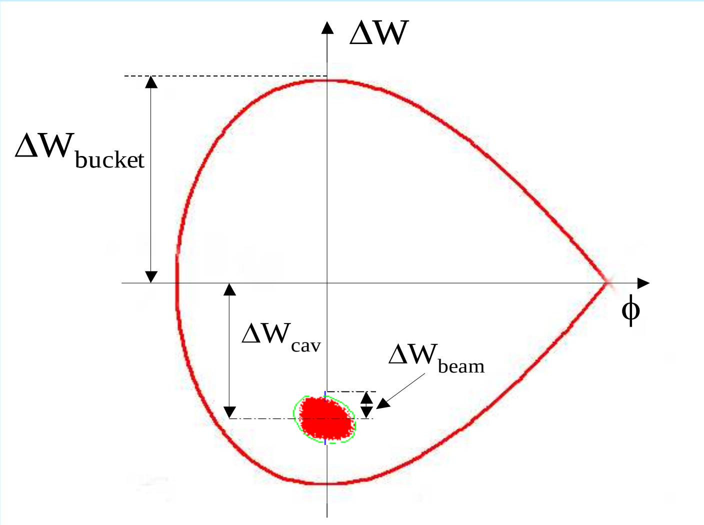
Beam lifetime in a repairable linac

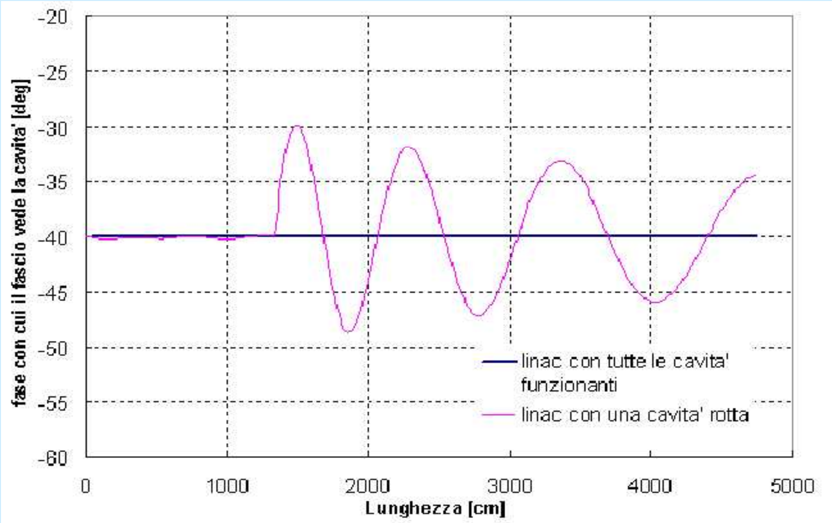
- Most beam interruptions come from failure of rf systems
- Beam lifetime can be improved significantly if the accelerator can tolerate the failure of one cavity and if this can be fixed on-line, e.g. replacing the power amplifier



Cavity constraints

- The linac can tolerate one cavity failure if the maximum energy gain per cavity is limited: $DW_{cavity} < DW_{bucket} - DW_{beam}$

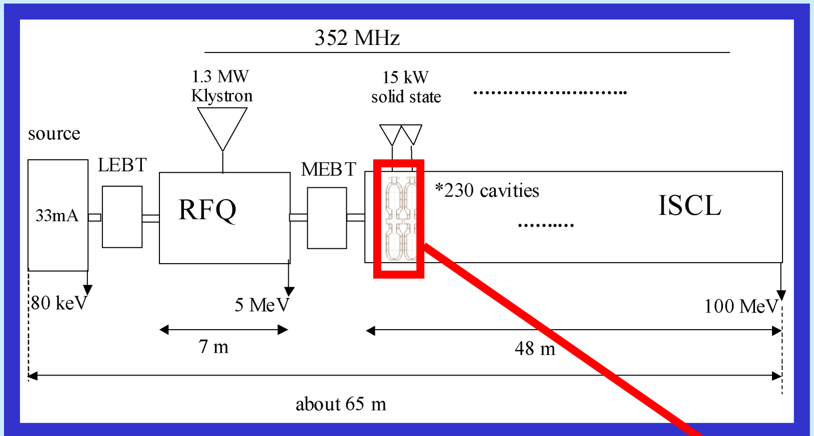




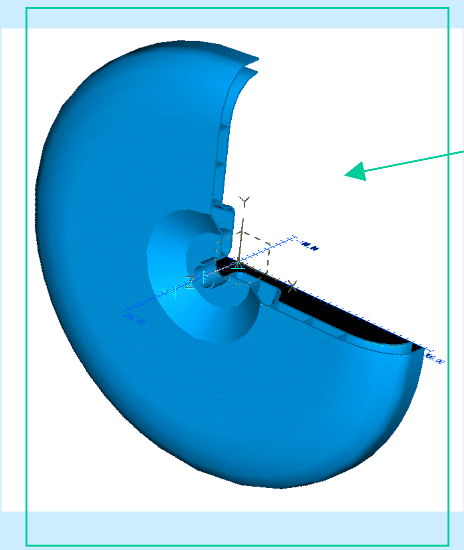
- Switching off one more cavity in the proper place allows to put back the beam in the center of the bucket
- Splitting the acceleration in many independent units, however, is not efficient in terms of R_{sh}: the superconducting solution is mandatory

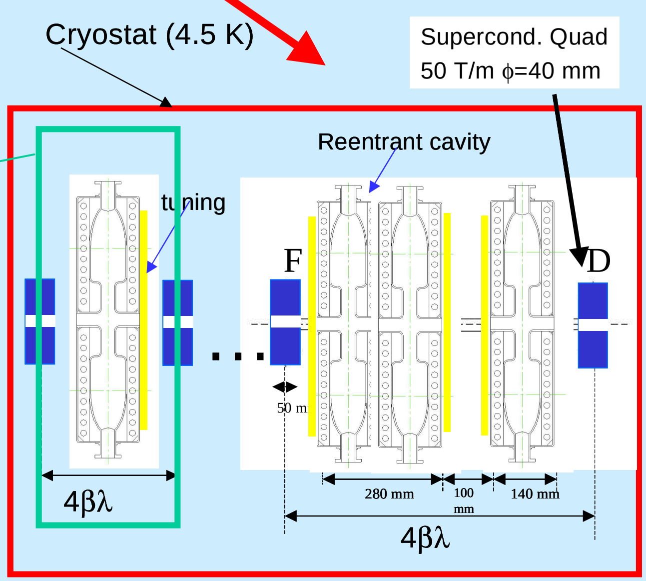
100 MeV TRASCO linac

tolerant of cavity failures



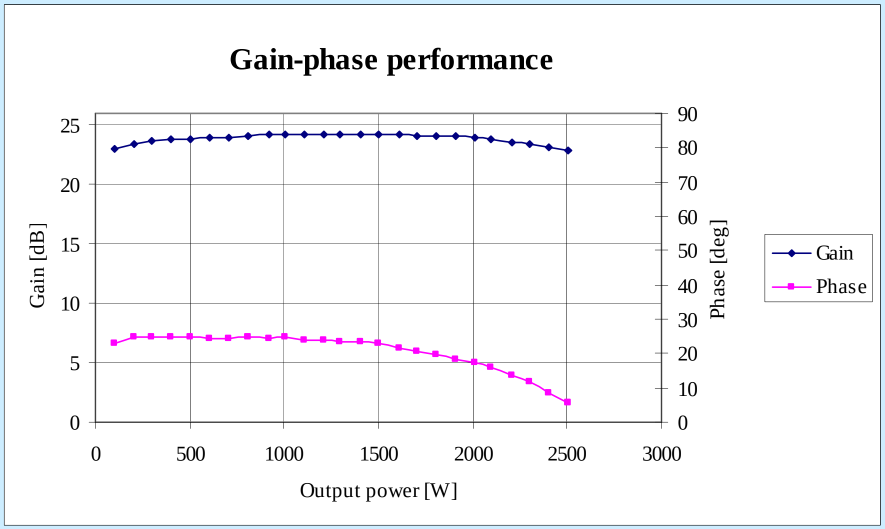
- 352 MHz, 30 mA proton RFQ
- 5-100 MeV ISCL
- FODO lattice
- wide-β SC cavities
- ΔW≤ 0.5 MeV/cavity
  (up to at least ~20 MeV)

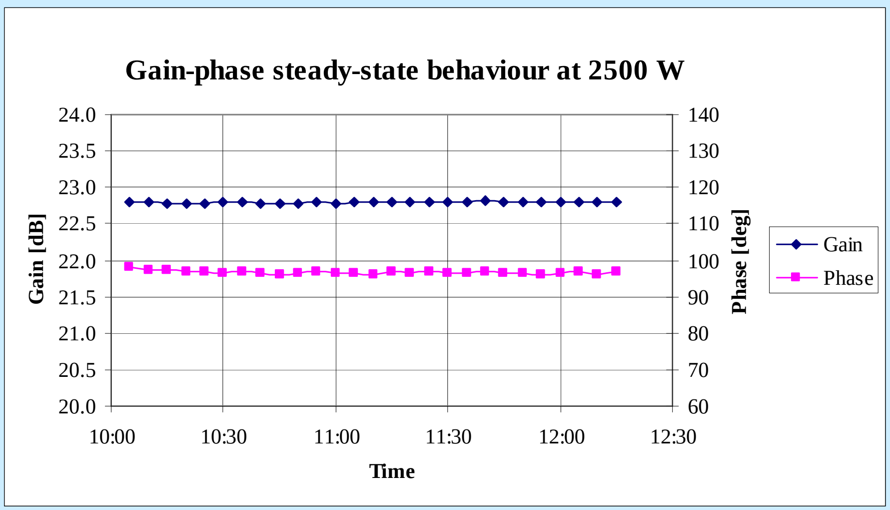


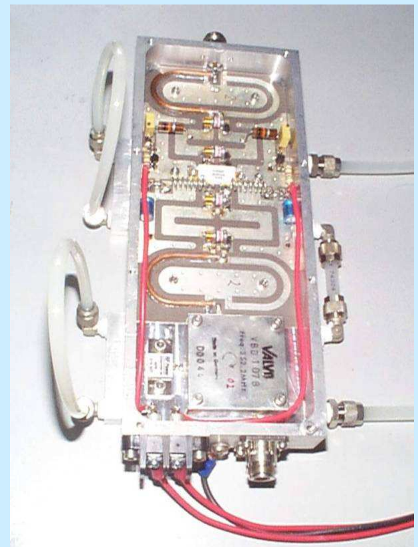


Required R&D:
- low cost - high reliability solid state amplifiers
- superferric quads
- <u>cavities</u>

Low cost - high reliability solid state amplifiers







- Modular construction
- MOSFET technology
- Circulators included
- Unconditionally stable
- Performance
- Reliability

- **1st 2500 W amplifier constructed and successfully tested**

going on:

- Testing in severe conditions
- Engineering for production
- Design of 5-20 kW units

Superferric quadrupole magnet

- **Developed at MSU-NSCL in collaboration with INFN-LNL for superconducting linacs**
- **Very compact, to be used inside cryostats-magnetic shielding required**
- **tested at 300K; test at 4.2 K to be done**

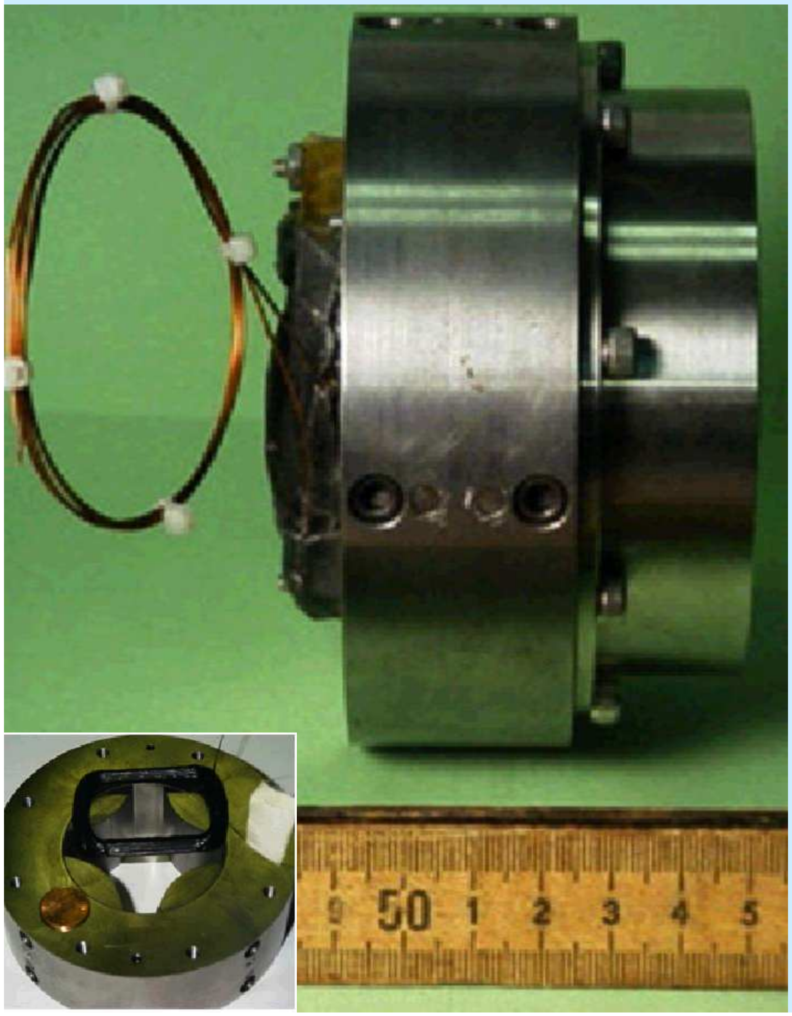
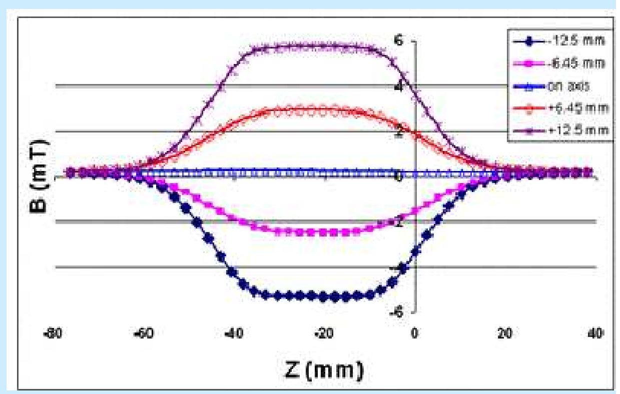
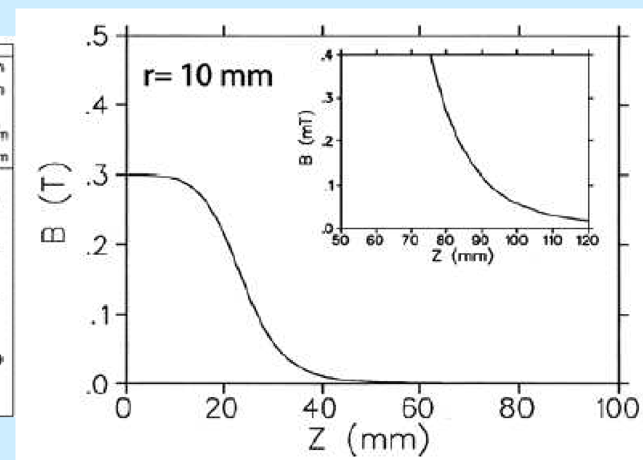


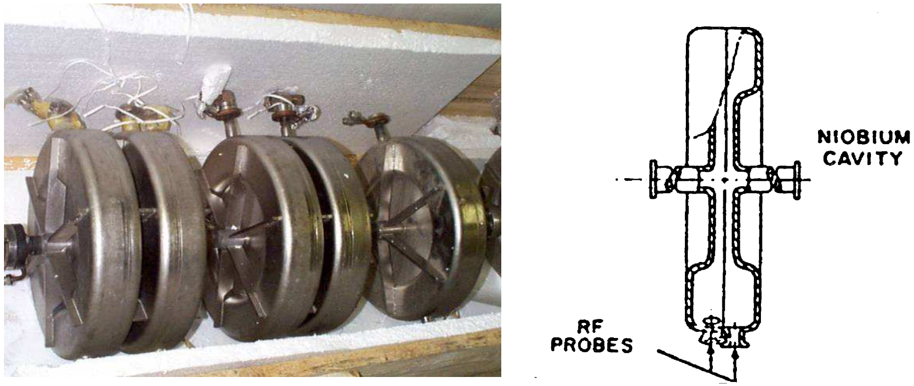
TABLE I
PHYSICAL PARAMETERS

Property	Specification
Effective length	50 mm
Radius	20 mm
Gradient	31 T/m
Turns of 0.431 mm wire	78
Current (2-D calculation)	63 A

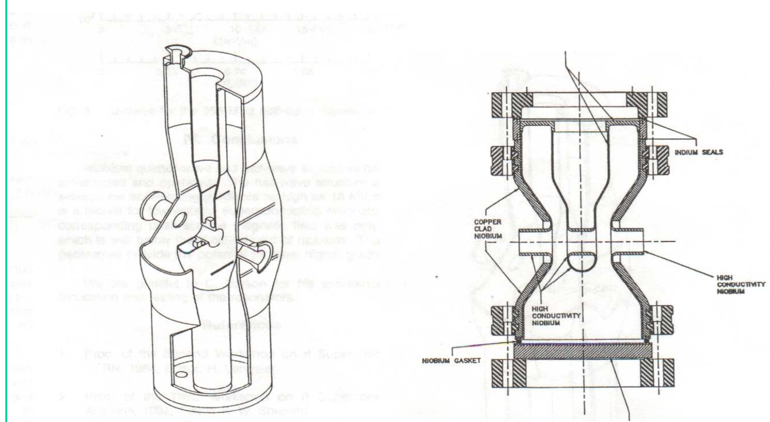




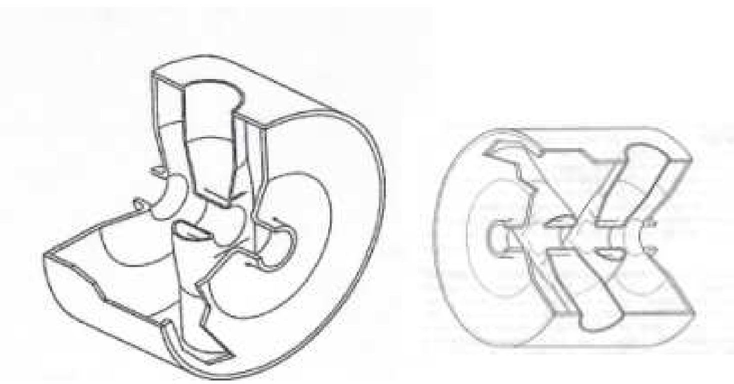
Examples of low-β cavities for proton beams



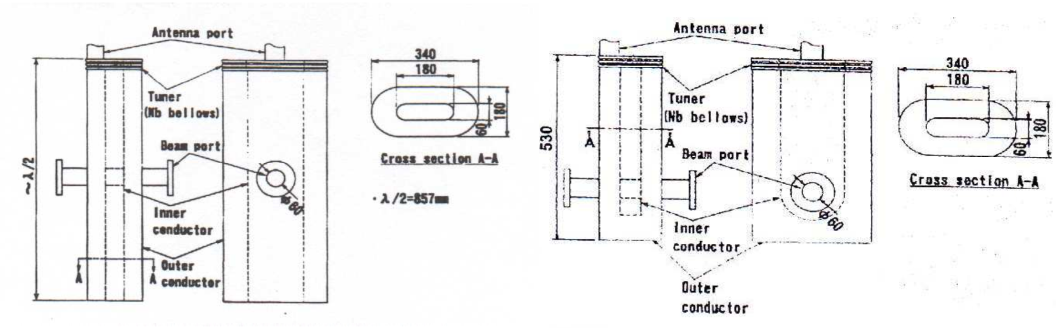
Stanford reentrant cavities (430 MHz)) -built and tested



ANL $\lambda/2$ (355 MHz) and $\lambda/4$ (400 MHz)-built and tested

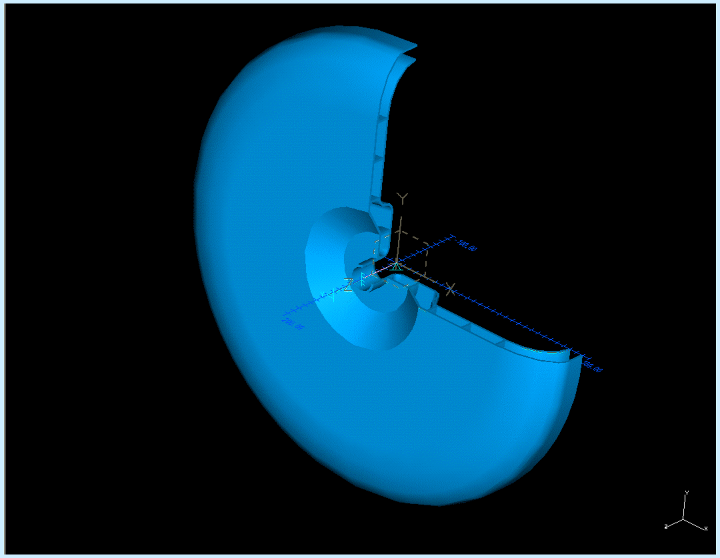


ANL 2-gap spoke (350 MHz) – built and tested
and 3 gap (850 MHz) spoke - proposed

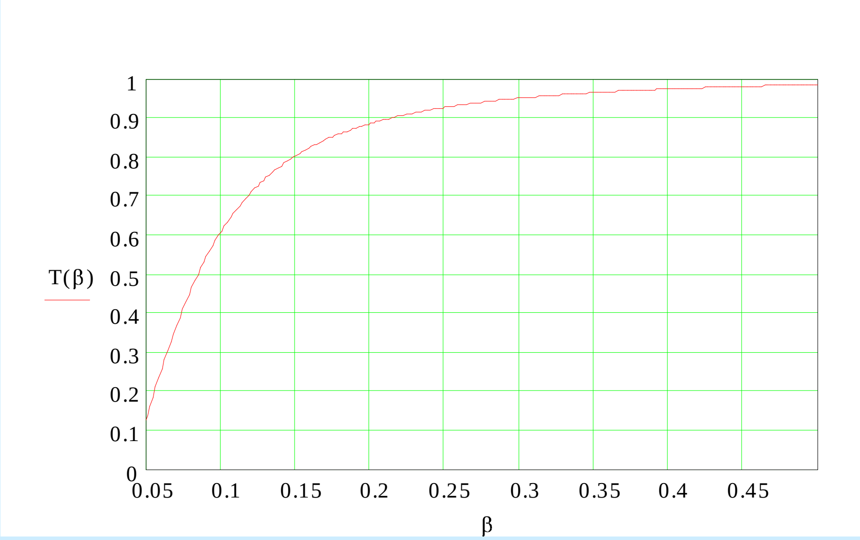


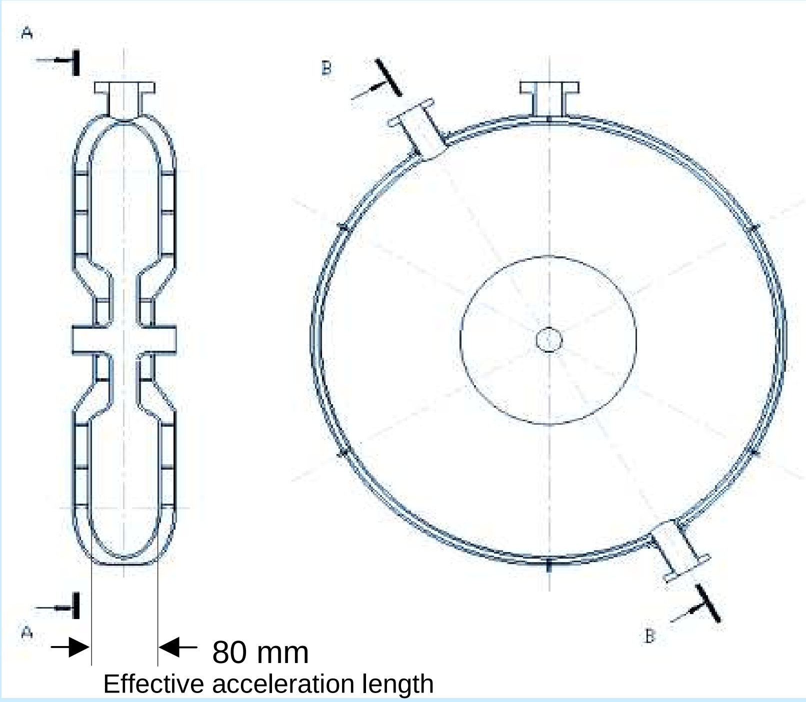
Toshiba $\lambda/2$ and $\lambda/4$ (175 MHz) - proposed

The TRASCO reentrant cavity

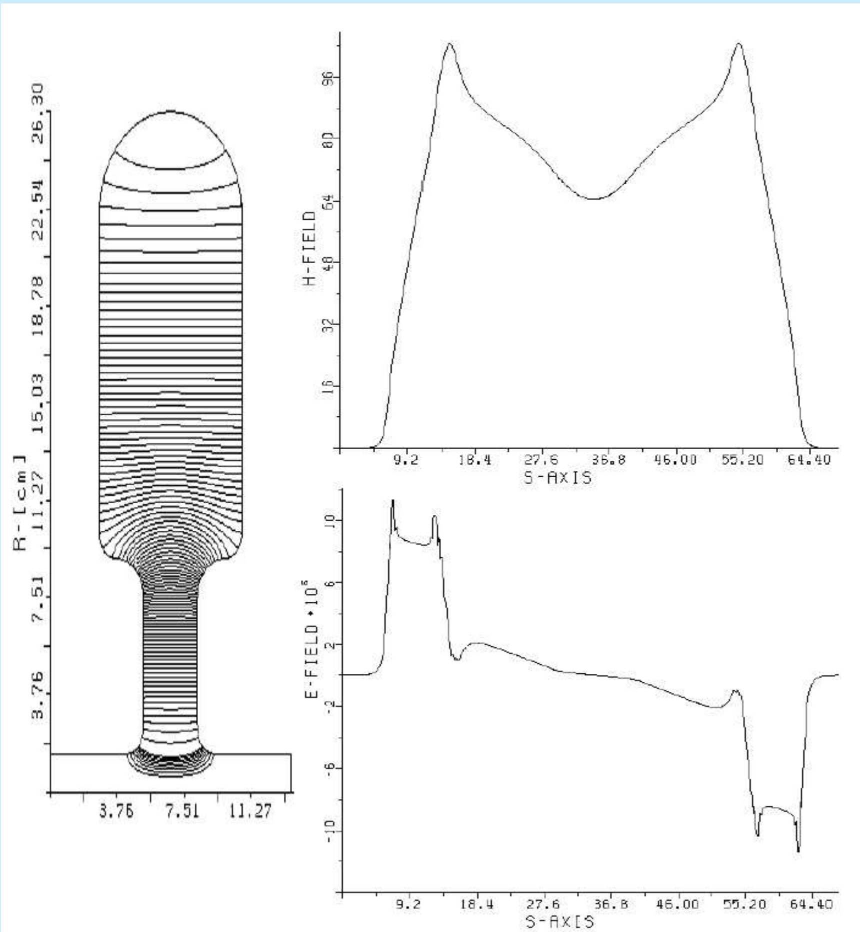


- 352 MHz cw
- single gap
- same cavity from 5 to 100 MeV
- Bore diameter 30 mm
- Field Axial symmetry





Rf design



In the final shape the intermediate step was smoothed to 60 deg

Main specifications:

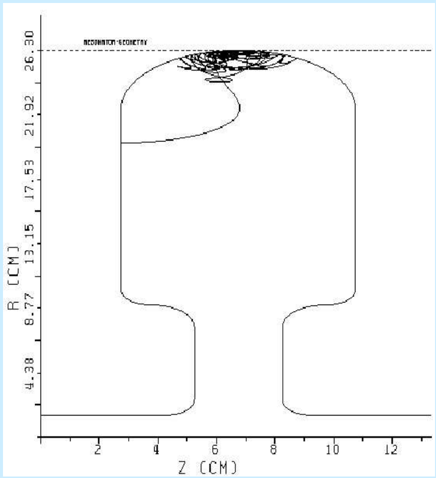
- 352 MHz, $\beta \geq 0.1$
- 30 mm bore diameter
- Inner length $\leq$ 80 mm
- $\Delta W \approx 0.5$ MV at 7W

Rf codes used:

- Superfish, HFFS

Cavity inner diameter	536	mm
Gap length	30	mm
Effective gap length	53	mm
Bore diameter	30	mm
Eff. acceleration length	80	mm
U/E_a^2	0.034	J/(MV/m)
E_p/E_a	3.0	
H_p/E_a	3.1	mT/(MV/m)
$\Gamma = R_s \times Q$	83	Ω
R_{sh}/Q	84	Ω

Multipacting simulations

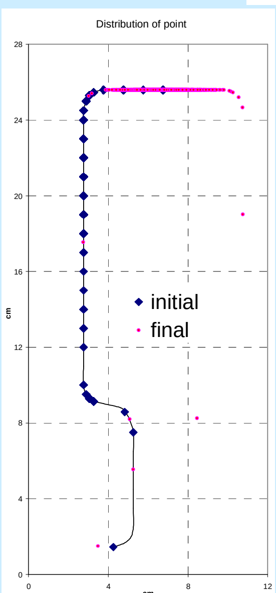


Simulation:

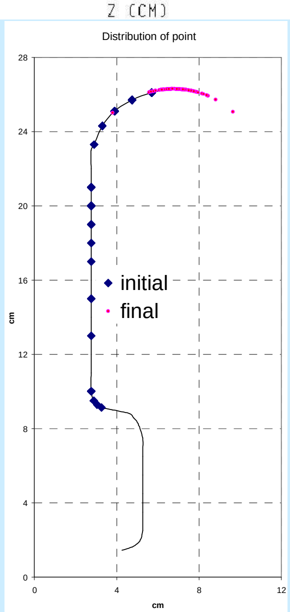
- code TWTRAJ (courtesy of R.Parodi, INFN Genova)
- ~60000 Runs
- 0.005 MV/m steps in E_a
- 5 mm steps in e^- starting position

Results:

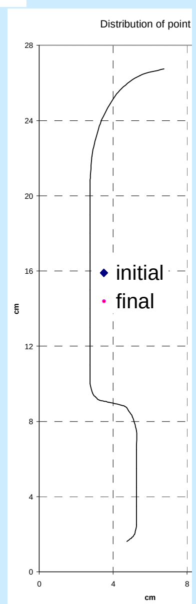
- MP negligible near the gap
- All levels at the equator: the equator profile is critical
- Ellipsoidal shape 1.5:1 free of MP



n. initial file	24020
n. selected file	1578
ratio	6.60%
range	0-25 MV/m



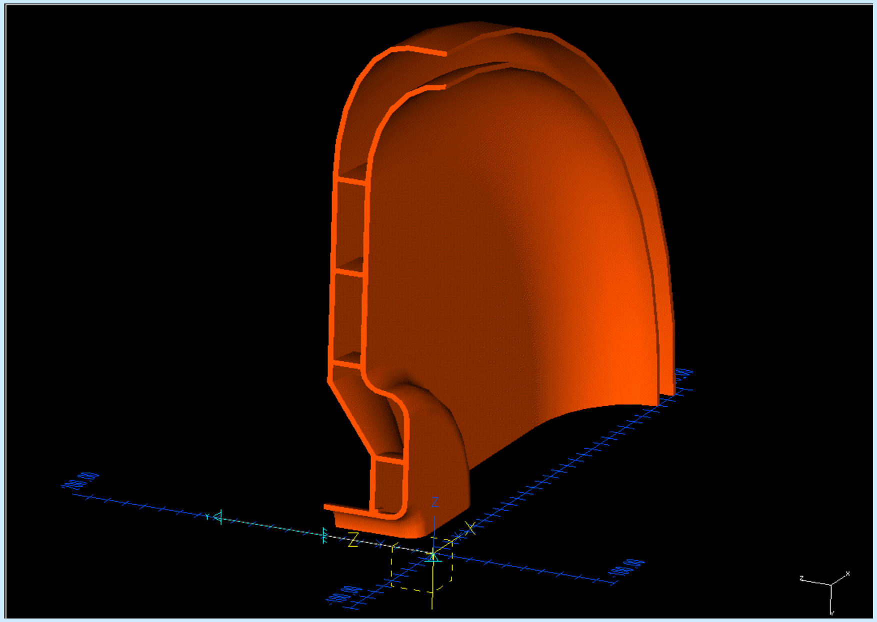
n. initial file	4840
n. selected file	95
ratio	2%
range	0-25 MV/m



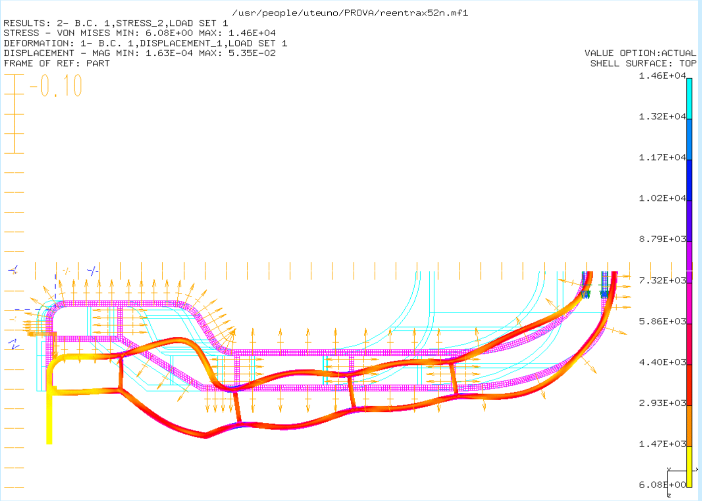
n. initial file	16516
n. selected file	0
ratio	0%
range	0-25 MV/m

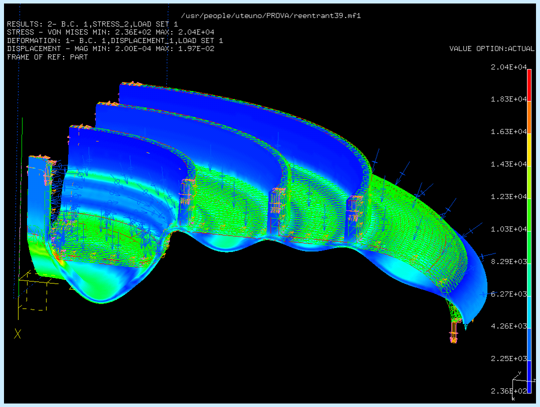
Total Number of runs with TVTRAG 45376

Mechanical design



- Main constraints:
  - -4 bar max pressure
  - -Physical length without tuner <130 mm
  - -Stability against He pressure fluctuations
  - -tunability
- Double wall structure with interconnecting rings
- 3 mm thick niobium sheet
  - -Inner shell: RRR>150 Nb
  - -Outer shell: normal grade Nb





- codes used:
  - Autocad (preliminary)
  - I-DEAS (main)

Mechanical construction

- Designed at LNL
- Built at Zanon, Schio (Vicenza) Italy
- CP treated at CERN
- Tested at LNL

Inner shell

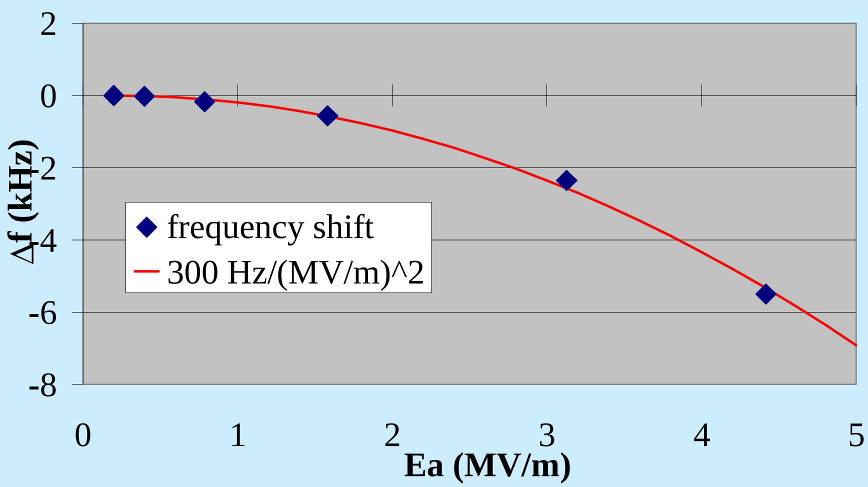
Detail of the interconnecting rings

Side view with rf ports

Final cavity after welding of the outer shell

Mechanical test results

(naked resonator - no tuner nor reinforcement)

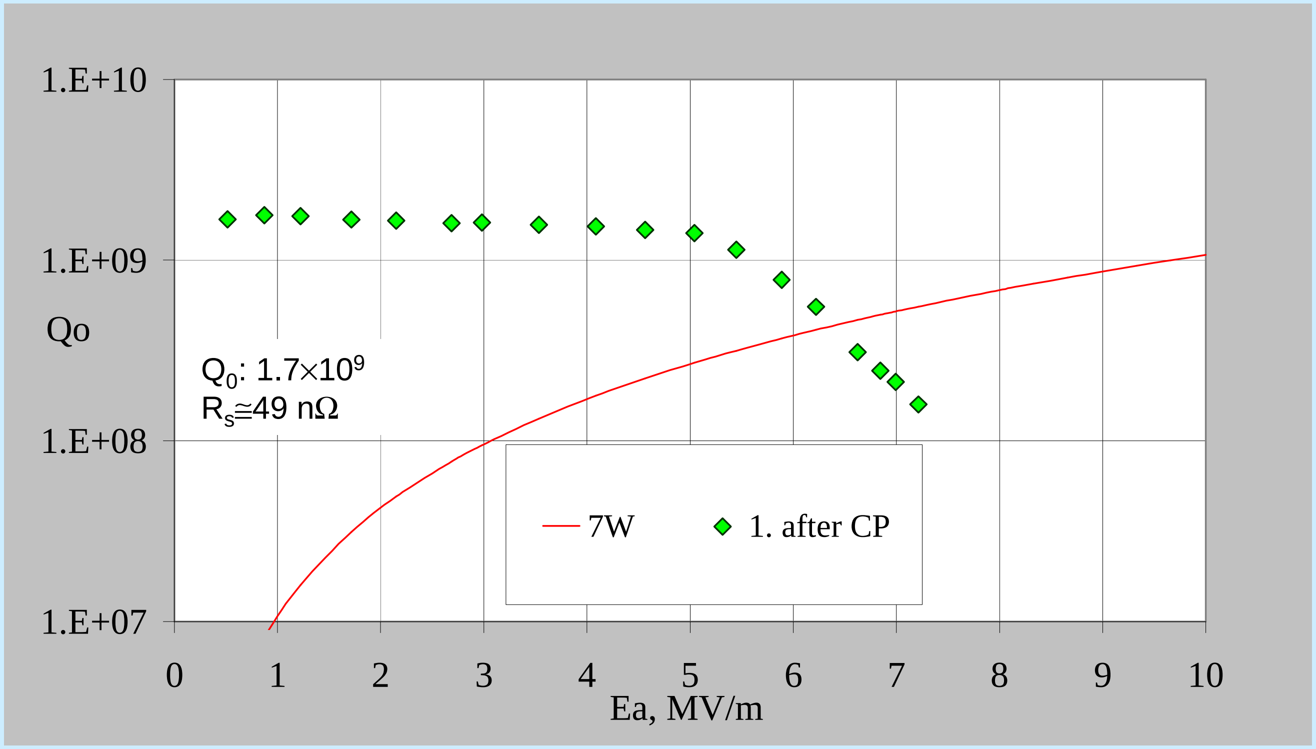


Lorenz force detuning test

parameter	measured	calculated	units
Rf frequency f final adjustment by plastic deformation foreseen	348.673	352	MHz
Frequency response to pressure df/dP from 0 to 1 bar in the helium vessel	~ -258	~ -140	Hz/mbar
Lorenz force detuning df/dE$_a$ measured from 0.2 to 4.4 MV/m	~ -300	~ -170	Hz/(MV/m)^2
Lower mechanical mode frequency f$_{mech}$	~ 195	~ 200	Hz

Superconducting Reentrant Cavity
1^{st} Rf test at 4.2K

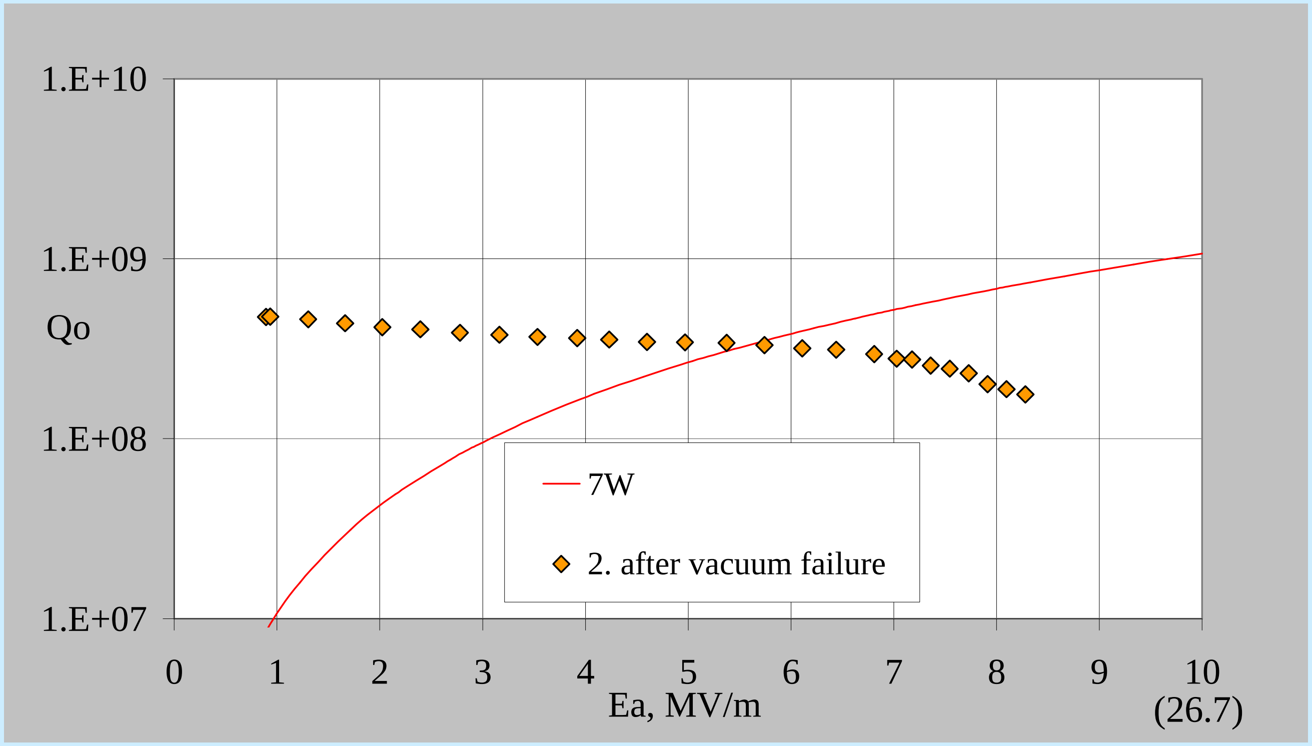
1^{st} test (after CP): capacitive coupler at the beam port
insufficient coupling: MP and Rf conditioning impossible



- Low field MP disturbing the test
- **High Q_0: 1.7×10^9 Low field R_s≅49 nΩ (R_{res} ≅ 10 nΩ)**
- Strong field emission above 5 MV/m

Superconducting Reentrant Cavity
2^{nd} Rf test at 4.2K

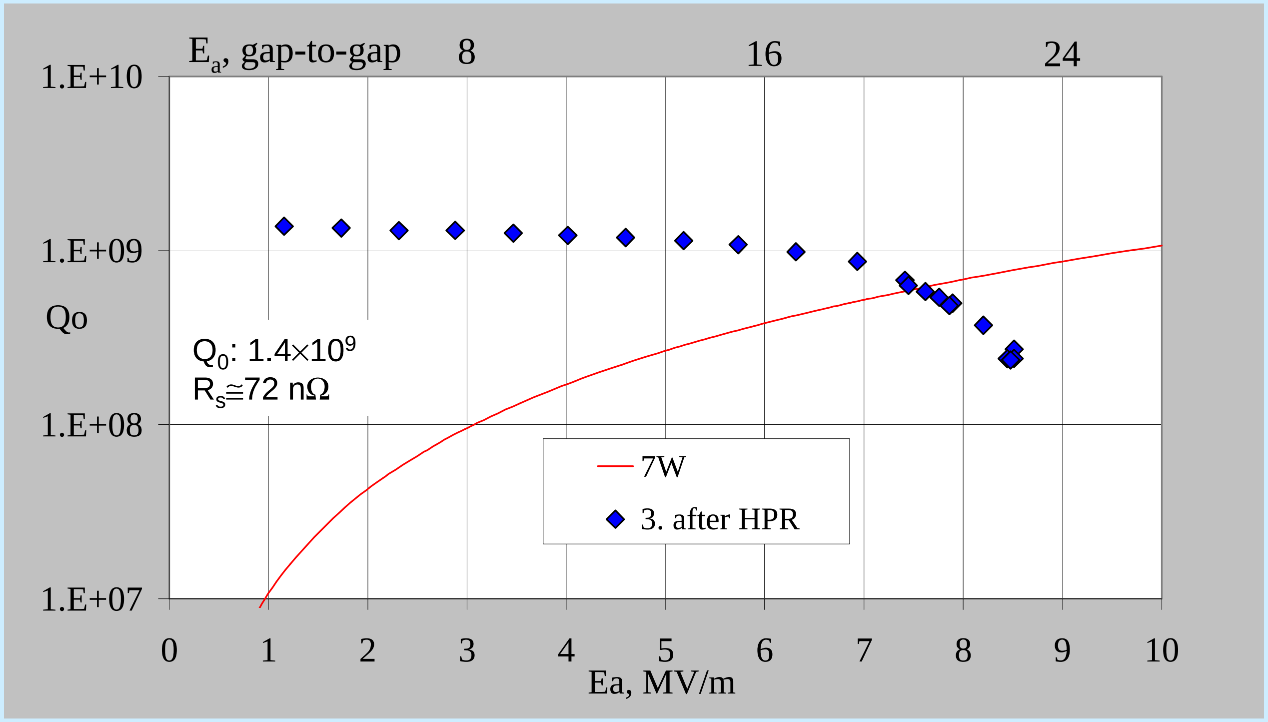
2^{nd} test (after severe vacuum failure due to rf feedthrough burning; cavity exposed to dusty air during repair). Coupler problems fixed; MP and rf conditioning possible



- low field MP easily conditioned
- contamination with dust and burning residues: Q degradation
- Increased E_a, FE conditioned

Superconducting Reentrant Cavity
3^{rd} Rf test at 4.2K

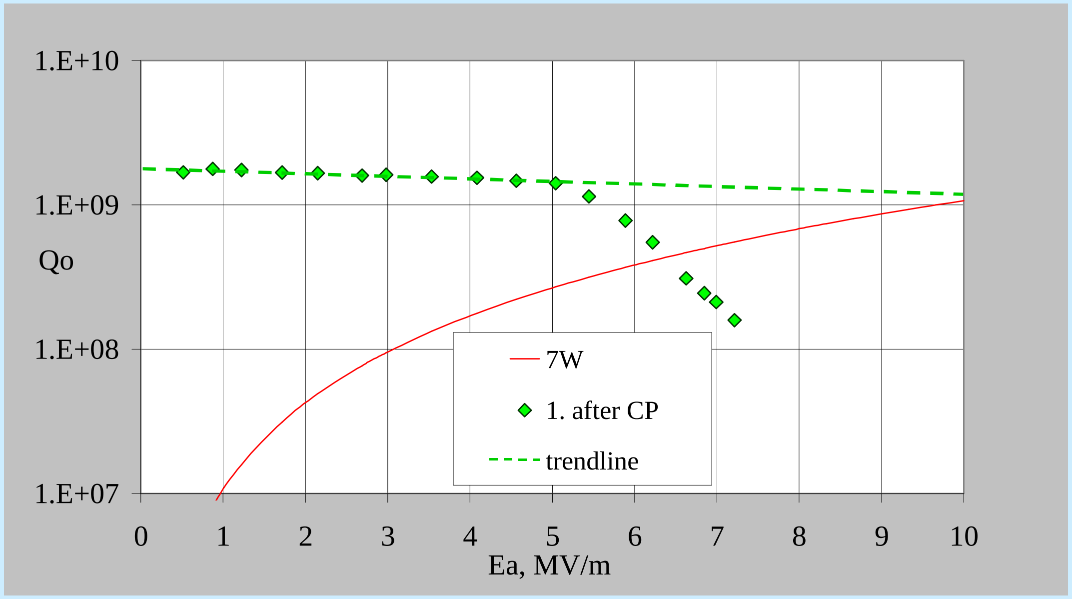
3^{rd} test after HPR of the cavity from outside through rf- and beam- ports.



- no MP level above 0.03 MV/m; low field levels easily conditioned
- Q_0 partially recovered: $R_s \cong 72$ nΩ ($R_{res} \cong 33$ nΩ)
- E_a=7.5 MV/m @ 7W (0.6 MV)

Next steps

- HPR from inside and test again
- Build and test the tuner
- Build a 5 kW rf coupler for the SPES project



Considering the surface resistance measured in the first test, and the relatively low peak fields reached, we can expect further improvement of the 7 W gradient

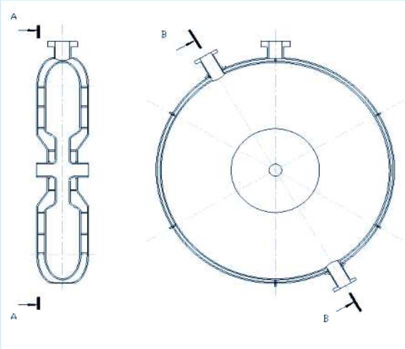
TRASCO Reentrant Cavity: advantages and drawbacks

Advantages:

- Short, compact and light, the He tank is part of the structure
- Relatively simple construction
- EM field perfectly symmetric
- very wide β acceptance
- Usable from very low energy (~5 MeV protons, β ~0.1)
- Low peak fields: possibility of high gradient

Drawbacks:

- not recommended for pulsed operation (Lorenz force detuning)
- relatively low energy gain/cavity
- Only inductive couplers to preserve compactness



Conclusions

- We have studied a high reliability design for the 30 mA, 5-100 MeV proton linac of TRASCO, based on reentrant cavities

- We have designed, built and tested a 352 MHz superconducting reentrant cavity
  - Short (13 cm without tuner) and very low β
  - free of dangerous multipacting
  - high gradient: 7.5 MV/m measured at the nominal power of 7 W
  - low peak fields: space for significant improvements

- Reentrant cavities possess some unique features that can be profitably used in low-β linacs, especially in the range $0.1 \leq \beta \leq 0.2$